

BAD : A BASIC LANGUAGE COMPILER FOR THE TMS 320 C31 DSK

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ABSTRACT

This paper presents a new programming language for the TMS 320 C31, which provides a better access to the processor hardware than the C language, and an algebraic syntax of runtime expressions, unlike TI's assembly language. Several examples show the readability of signal processing algorithms implemented with this Basic-like language.

1. INTRODUCTION

The TMS 320 C31 floating-point DSP [11] is a versatile and powerful 32 bits signal processor. As the forthcoming C33, this component belongs to the third generation family of DSP's, which can bring low-cost industrial solutions for signal processing [7, 12], process control [2, 13] and instrumentation applications.

Of course, a necessary condition to meet this goal is the availability of accessible development systems, for an easy code generation. For the time being, only the assembly [14] and the C [15] programming languages are proposed by Texas Instruments. Both languages have well known advantages and drawbacks. Coding directly with the assembly language yields shorter and faster code, but requires a detailed knowledge of both the architecture and the instruction set of the DSP. Because of the non-orthogonality of the instruction set (all addressing modes are not allowed for all instructions), this may require several trial and error loops. Designing relevant applications in a reasonable amount of time is therefore possible for experienced users only, and is out of reach for many applications engineers and many high school students. Choosing the C language is safer, requires less code rewriting when the algorithms are modified, and provides an easier readability of the code, at the expense of a larger and slower binary code. However, one may ask if the C language is a good choice when instructions such as [5]

```
volatile int *PBASE=(volatile int *) 0x808000 ;
```

are required just to make the PBASE variable point to the address 808000h. More generally, the particular features that distinguish DSP's from conventional microprocessors do not seem to be easily used through the standard ANSI C [9]. Using interrupts in C is also possible, but certainly not simple [4].

This paper reports the design of a new compiler, which allows signal processing applications to be written more easily. This freely available compiler [3] should allow the use in realistic projects of the TMS320 C31 starter kit (DSK), in a digital signal processing laboratory [5], even at an undergraduate level. Some of its elements and ideas are borrowed from the Parallax Basic [8] and from the MATLAB programming language [16]. In section 2, we show that this compiler provides many possibilities of high level general purpose programming languages, and generates efficient assembly language source code. Section 3 shows how it can suit to the implementation of signal processing applications.

2. THE BAD FUNCTIONALITIES

The aim of this section is to show the simplicity of the proposed language, and its appropriateness to signal processing algorithms. The translation mechanisms of the compiler are also shown through several examples.

Every BAD source file must start by a program header which begins by the keyword `dsbasic`, followed by the target identifier `c31dsk`. For the time being, this is the only target identifier allowed, but future extensions of the compiler could be possible for other C31 boards and/or other DSP's. Comments (starting by a quote) are highly advised in this program header.

After this prologue, constants and variables declarations may be found. As the internal registers of the C31, the BAD compiler provides only two scalar data types : 32 bits signed integers (`int`), and 32 bits floating-point real numbers (`float`). As in PBASIC [8], all variables must be declared before they are used, and are global (variables known only locally within subroutines do not exist). Constants and variables are simply defined respectively by the keywords `const` and `var`. Each variable is initialized to zero, unless the data type is followed by an optional initial value, as in the following source code example:

```
Const    length 10      ' constant length equals 10
Var      y float 5       ' one float
Var      ~y1 float 17    ' another float
Var      j int           ' an integer
```

The object code in assembly language produced by the compiler for these Basic instructions is:

```
length .set    10      ; const length 10
y      .float   5       ; var y float 5
y1     .float  17       ; var ~y1 float 17
j      .word    0       ; var j int
~y     .word    y       ; address of y
~j     .word    j       ; address of j
```

The compiler is not case sensitive, and all upper case characters used in the source code are converted into lower case ones. It should be underlined that each Basic instruction is recalled in comments, so as to provide more intelligibility (these comments will be sometimes removed below, so as to respect the format of the proceedings). The assembly language variables `_y` and `_j` hold the addresses of the variables `y` and `j`, allowing their access by indirect addressing modes. These localization variables are not generated when the Basic variables are preceded by a tilde, as for `y1`.

Moreover, so as to use as much as possible the eight main registers of the DSP, the variables `x0`, `x1`, `x2`, `x3` and `i0`, `i1`, `i2`, `i3` are predefined real and integer variables. These variables are alias names of the internal registers `R4`, `R5`, `R6` and `R7`, which can be used to store either real or integer values.

binary operators allowed for both real and integer variables	
+	arithmetic addition
-	arithmetic subtraction
*	arithmetic multiplication
binary operators allowed for integer variables only	
&	logical and
	logical nand
~	logical or
#	logical xor

Table 1: allowed binary operators.

The first four registers are used by the compiler as scratchpad registers. Using these variables is highly advised for a shorter code length, since all variables defined by the user are placed in memory. But of course `x0` and `i0` can not be used at the same time, since they both refer to the same R4 register.

Defining arrays is also possible, either by writing the appropriate number of initial values, or by writing the size of the array between brackets, as in the following example:

```
var Primes      int      2,3,5,7,11
var SignalSegment float(75)
```

The first possibility may be preferred for small arrays, whereas the second one suits to large ones. The object code in assembly language produced by the compiler for these Basic instructions is:

```
primes .word 2,3,5,7,11
signalsegment
        .loop 75
        .float 0
        .endloop

_primes .word primes
_signalsegment .word signalsegment
```

The first index value of an array is always 0. The 0th cell of an array can be referred by using just the array's name, without an index value. Caution should be made about arrays, because the compiler does not test the access to out-of-range locations, so as to give the programmer more freedom (and hence more misleading opportunities).

Both variables and constants can be used in runtime math or logical expressions, which can be of three kinds only :

```
var1 op= value,
var1 op= var2
var1 op= var2 binop var3
```

where `var1`, `var2` and `var3` are three variable names, `binop` is a binary operator, and `op=` is an assignment operator. The allowed binary operators and assignment operators for real and integer variables are listed in tables 1 and 2. The following basic instructions are examples of legal statements, in which the semi-colons are statement separators, pulling two instructions written on the same line apart.

```
y=length ; y*=1.5 ; x0=6
j+=1; y(j) +=x0+y; x0!=y(1)
```

and the object code produced by the compiler for these instructions is:

```
ldi      @_y, AR1      ; y=length
ldf      length, R0
stf      R0, *AR1

ldi      @_y, AR1      ; y*=1.5
```

assignment operators allowed for both real and integer variables		
ass. op.	example	
=	<code>x0=2</code>	<code>x0 = 2</code>
+=	<code>x0+=2.5</code>	<code>x0 = x0 + 2.5</code>
-=	<code>x0-=2.1</code>	<code>x0 = x0 - 2.1</code>
=	<code>x0=5.0</code>	<code>x0 = x0 * 5</code>
!=	<code>x0!=y</code>	<code>x0 = abs(y)</code>
assignment operators allowed for integer variables only		
ass. op.	example	
&=	<code>i &= 2</code>	<code>i = i and 2</code>
=	<code>i = 2</code>	<code>i = i and 2</code>
~=	<code>i ~= 2</code>	<code>i = i or 2</code>
#=	<code>i #= 5</code>	<code>i = i xor 2</code>

Table 2: allowed assignment operators.

```
ldf      1.5, R0
mpywf3   R0,*AR1, R0
stf      R0, *AR1

ldf      6, R4      ; x0=6

ldi      @_j, AR1    ; j+=1
ldi      1, R0
addi3    R0, *AR1, R0
sti      R0, *AR1

ldf      R4, R0      ; y(j) +=x0+y
ldi      @_y, AR1
ldf      *AR1, R1
addf3    R1, R0, R0
ldi      @_j, AR2
ldi      *AR2, IR0
addf3    R0, *+AR1(IR0), R0
stf      R0, *+AR1(IR0)

ldi      @_y, AR1    ; x0!=y(1)
ldi      1, IR0
ldf      *+AR1(IR0), R0
absf     R0, R0
ldf      R0, R4
```

The conciseness of the translation of `x0=6` is evidenced when compared to the one for `y=length`. The compiler has optimized the translation of `y(j) +=x0+y`, detecting that both `y(j)` and `y` belong to the same array.

This reduced number of runtime expression structures may seem very restrictive, but this limitation can be justified by several arguments :

- The use of immediate values is limited to the first statement only, because the C31's architecture allows immediate addressing only with 16 bits integer and floating point numbers. Such instructions must therefore be used with care, and variables used as much as possible.
- Integer or float divisions are not allowed, because the C31 DSP does not have these operations in its instructions set. They are implemented however by special subroutines.
- The limitation of runtime expressions to simple binary operators imposes the user to expand more complicated expressions into simple ones, which are nearer to the DSP instructions set. From an educational point of view, this can show more clearly what a DSP can do. This expansion can also give a better view on the complexity of an algorithm.

- Since there is only one binary operator per instruction, a precedence rule does not need to be defined, which reduces the potential for misinterpretation.
- As this, the legal statements allowed by the compiler are very closed to the algebraic syntax of the instructions of the assembly language for the DSP's designed by Analog Devices, such as the AD21020 [1].
- Since the instructions of the source program are simple, the object code produced by the compiler can be easily understood, allowing a peephole optimization.

It should be also underlined that both the value *and the address* of user defined variables can be modified by runtime expressions, thanks to the @ operator, as in the example below :

```
@ScannedValue=@RealArray
ScannedValue += 5.6 ; @ScannedValue+=1
```

The object code produced by the compiler for these instructions can be found in [3]. This possibility should allow dynamic memory allocation mechanisms, and as much flexibility as available with pointers in the C language.

Flow control statements are possible thanks to labels, which must start by a colon. The existence of labels allows :

- unconditional jumps, with the goto instruction. As an example, the following Basic instructions,


```
:LoopStart
x0 += x1*x2 ; goto LoopStart
```

 will be translated into the following object code:


```
loopstart      ; :loopstart
ldf            R5, R0 ; x0 += x1*x2
ldf            R6, R1
mpyf3         R1, R0, R0
addf3         R0, R4, R0
ldf            R0, R4

br            loopstart ; goto loopstart
```
- conditional statements, which, as in PBASIC [8], are implemented by the following syntax:

```
if condition then goto label
```

For example, the instruction

```
if x0>y then goto LoopStart
```

will be translated into

```
ldf            R4, R0
ldi            @_y, AR1
ldf            *AR1, R1
cmpf          R1, R0
bgt            loopstart
```

- subroutine calls, with the gosub instruction. A subroutine must start by a label definition, and ends by a return. So as to take advantage of a possibility of the C31 instructions set, subroutines may be conditionally aborted thanks to the returnif *condition* structure. Arguments and returned datas are gathered in an array, whose name *must* start by the subroutine name, followed by srda (for *subroutine data exchange*). It is advised to put the arguments first, followed by the outputs. Inside itself, a subroutine accesses to its srda by the predefined real and integer arrays fsrda and isrda, as in the following example,

```
Var MySubroutineSrda float 0, 0
...
gosub MySubroutine
...
:MySubroutine
fsrda(1)=fsrda(0)+x0;
return
```

which will be translated into:

```
mysubroutinesrda .float 0, 0
_mysubroutinesrda .word mysubroutinesrda
...
push            ar0 ; gosub mysubroutine
ldi            @_mysubroutinesrda, ar0
call           mysubroutine
pop            ar0

...
mysubroutine      ; :mysubroutine
; fsrda(1)=fsrda(0)+x0
ldf            *AR0, R0
ldf            R4, R1
addf3         R1, R0, R0
ldi            1, IR0
stf            R0, *+AR0(IR0)

rets            ; return
```

- simple access to interruptions, thanks to predefined labels, whose names are taken from the constructor's literature (see [11], p 7-26). Interrupts start by a predefined label, and end by a reti instruction. Conditional ends of interrupt are also allowed by the retiif *condition* structure. As an example, the following instructions

```
:xint0
x0+=2.5 ; reti
will be translated into
; this program uses the xint0 interruption
.start "xint0sect", 0x809FC5
.sect "xint0sect"
br xint0

.text
xint0
ldf            2.5, R0 ; :xint0
addf3         R0, R4, R4

reti            ; reti
```

Moreover, data-driven flow control is also possible by the goto *var1* and gosub *var2* statements. In the first case, *var1* must be an integer holding the address of a label. In the second statement, *var2* must be an array of two integers. The first one holds the address of the subroutine, and the second one the address of the "srda". The labels hold in *var1* and *var2* must be defined by two successive colons, as in the example below:

```
Var mySub2Srda float 0, 0
Var RightLabel int 0
Var RightSub int 0, 0
...
::GoodPlace
RightLabel = @GoodPlace
RightSub(0) = @MySub2 ; RightSub(1) = @MySub2Srda
gosub RightSub
...
goto RightLabel
...
::MySub2
fsrda(1)=fsrda(0)*x0 ; return
```

The object code produced by the compiler for these instructions can be found in [3]. Such possibilities, which do not exist in the C language, can efficiently replace multiple choice conditional statements such as the switch structure in MATLAB 5 [16].

Finally, assembly language instructions may be included, preceded by the asm keyword. This can make the access to the hardware features of the DSP easier. Some parts of code where the DSP spends most of its time may also be advantageously written in assembly language.

3. DESIGNING SIGNAL PROCESSING APPLICATIONS WITH BAD

For a fast and easy design of signal processing applications, an engineer needs not only an easy-to-use programming language, but also a library of the most usual transcendent functions (sin, cos, log, exp ...) and of the most frequently used signal processing tools (FIR and IIR filters, FFT, DCT, ...). Most of the transcendent functions are currently available, whereas only some of the signal processing building blocks are already implemented. But we hope that more and more will be available thanks to cooperative work. Designing a signal processing application will therefore only require to code the specific features, integrating safe general purpose functions written by experts.

As an example of the use of the proposed language for the implementation of signal processing algorithms, the main core of a tracking Kalman filter [10] is presented below. The complete program, together with more explanations and the corresponding object code, can be found in [3], from where other examples can also be retrieved.

```

dspbasic c31dsk
' tracking kalman filter, F. Auger, nov 1999

' elements of the covariance matrices
var p11pred float ; var p11est float 10
var p12pred float ; var p12est float 0
var p22pred float ; var p22est float 10
' Kalman gains
var k1 float ; var k2 float

var quarterqr float ' 0.25* q/r,
var error float ' error=y-H*x

var FinvSrda float 0,0 ' srda of finv
var FinvMask int 0xFF7FFFFF ' mask used by finv

var SETSP int 0E970300h ' serial line config
var AICSETSRDA int 1,5,0x1f,0x99 ' srda of aicset
var twaitsrda int 0 ' useless srda
var AICIOSRDA int 0,0 ' DAC ADC

:InitInterrupt
' scf=625 kHz, Fs=20161 Hz, full scale
gosub aicset ' init of the AIC in interrupt mode
:MainLoop
' prediction step :
' x1[k+1|k]=x1[k|k]+x2[k|k] and x2[k+1|k]=x2[k|k]
' x1[k|k] and x1[k+1|k] are stored in x1
x1+=x2 ' x2[k|k] is stored in x2 and not modified

' computing the covariance matrix of the
' predicted state ; x0 is used as scratchpad
' p11[k+1|k]=p11[k|k]+2*p12[k|k]+p22[k|k]+0.25*q
p11pred=p11est+p22est; p11pred+=p12est+p12est
x0=quarterqr ; p11pred+=x0

' p12[k+1|k]=p12[k|k]+p22[k|k]+0.5*q
x0*=2; p12pred=p12est+p22est; p12pred+=x0

x0*=2; p22pred=p22est+x0 ' p22[k+1|k]=p22[k|k]+q

' K[k+1]=P[k+1|k]*H'/(H*P[k+1|k]*H'+r)
' first compute x0=1/(p11pred+r)
FinvSrda(0)=1; FinvSrda(0)+=p11pred; gosub Finv
x0=FinvSrda(1); k1=p11pred*x0; k2=p12pred*x0

aiciosrda(0)=x1 ' predicted position as output
idle ' wait for an interrupt
error=aiciosrda(1)-x0; ' correction step

```

```

' xi[k+1|k+1]=xi[k+1|k]+ki[k+1]*e[k+1], i=1,2
x1+=k1*error ; x2+=k2*error

' covariance matrix of the estimated state
x3=p12pred; x3*=x3*x0; p22est=p22pred-x3
p12est=p12pred*x0 ; p11est=p11pred*x0

goto MainLoop

:xint0 ' interrupt from the AIC
' call aicio, and return from interrupt
gosub aicio ; reti

```

4. CONCLUSION

The proposed Basic language compiler should avoid many students to be scared away by the implementation of signal processing algorithms on DSP's [17]. When compared to the assembly language, it should also make generation, testing and maintenance of large programs cheaper and less tedious.

5. REFERENCES

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